

**American Conference on Neutron Scattering
(Knoxville, 6/02)**

Clifford G. Shull Award Announcement

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Gaithersburg, MD 20899**

The Nobel Prize in Physics 1994



Clifford G. Shull, MIT, Cambridge, Massachusetts, USA, receives one half of the 1994 Nobel Prize in Physics for development of the neutron diffraction technique.



S Shull made use of **elastic scattering** i.e. of neutrons which change direction without losing energy when they collide with atoms.

Because of the wave nature of neutrons, a diffraction pattern can be recorded which indicates where in the sample the atoms are situated. Even the placing of light elements such as hydrogen in metallic hydrides, or hydrogen, carbon and oxygen in organic substances can be determined.

The pattern also shows how atomic dipoles are oriented in magnetic materials, since neutrons are affected by magnetic forces. Shull also made use of this phenomenon in his neutron diffraction technique.



Clifford G. Shull (left) and E.O. Wollan (right) working in the neutron diffraction laboratory at the University of Illinois, Urbana, Illinois.

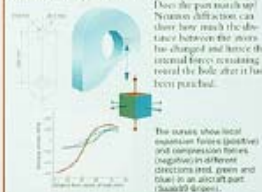
Neutrons see more than X-rays

X-rays are scattered by electrons; neutrons by atomic nuclei. With X-rays it is easy to see atoms that have many electrons. Hydrogen, for example, which has only one electron, is too small to see. With neutrons, all kinds of atoms are visible.



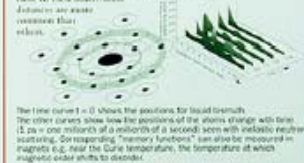
Neutrons reveal inner stresses

A hole has been punched in an important metal aircraft part.



Neutrons show what atoms remember

Of their earlier positions when they move randomly in relation to each other in liquids and solids. Even here there is in fact some local order. The atoms cannot move infinitely.



Neutrons behave as particles and as waves

Neutrons reveal structure and dynamics

Neutrons bounce against atomic nuclei. They also react to the magnetism of the atoms.

Neutrons show where atoms are

When the neutrons collide with atoms in the sample material, they change direction (are scattered) - **elastic scattering**.



Detectors record the directions of the neutrons and a diffraction pattern is obtained. The pattern shows the positions of the atoms relative to one another.

Crystal that sorts and forwards neutrons of a certain wavelength (energy) - **monochromatized neutrons**

Research reactor



3-axis spectrometer

Neutrons show what atoms do

3-axis spectrometer with rotatable crystals and rotatable sample



Crystal that sorts and forwards neutrons of a certain wavelength (energy) - **monochromatized neutrons**

When the neutrons penetrate the sample they start or cancel oscillations in the atoms. If the neutrons excite phonons or magnons they themselves lose the energy these absorb - **inelastic scattering**



Changes in the energy of the neutrons are first analysed in an analyser crystal...

...and the neutrons then counted in a detector.

Bertalan N. Brockhouse, McMaster University, Hamilton, Ontario, Canada, receives one half of the 1994 Nobel Prize in Physics for the development of neutron spectroscopy.



B Brockhouse made use of **inelastic scattering** i.e. of neutrons, which change both direction and energy when they collide with atoms. They then start or cancel atomic oscillations in crystals and record movements in liquids and melts. Neutrons can also interact with spin waves in magnets.

With his 3-axis spectrometer Brockhouse measured energies of phonons (atomic vibrations) and magnons (magnetic waves). He also studied how atomic structures in liquids change with time.

How it started

Brockhouse and Shull made their pioneering contributions at the first nuclear reactors in the USA and Canada back in the 1940s and 1950s. It was then that the resources of the reactors became available for peacetime research.

... how it continues

Thousands of researchers are now working at the many neutron research centers throughout the world. New and very advanced neutron scattering installations have been built and more are planned in Europe, the USA and Asia. At these super-installations the researchers are studying the structure of new ceramic superconductors, molecular movements on surfaces of interest for catalytic exhaust cleaning, virus structures and the connection between the structure and the elastic properties of polymers.



KUNGL. VETENSKAPSAKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

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Further reading:

- L.J. Hughes *The Nuclear Reactor as a Research Instrument*, SCIENTIFIC AMERICAN, VOL. 194, AUGUST 1953, P. 21.
- H. Lengeler and J.L. Finney, *The European Spallation Source*, EUROPEAN NEWS, VOL. 25, P. 7, 1994.
- Information about the Nobel Prize in Physics 1994 (premiere), THE ROYAL SWEDISH ACADEMY OF SCIENCES.

Nobel Foundation poster depicting the 1994 Nobel Prize in Physics.

I am Bob Shull. I lead a group on magnetic materials at the National Institute of Standards and Technology. I have been one of the luckiest people alive. I was one of the sons of Cliff and Martha Shull!!! I don't know how I got to be so lucky, but someone up there must have been looking out for me!!! There is obviously no substitute to picking your parentage well!!!



Cliff and Martha-Nuel Shull hiking in the White Mountains in the early 1950s.

Cliff Shull and
son Robert in
1949.



Secondly, both my brothers and I are ***delighted*** that the National Scattering Society of America (NSSA) has chosen to honor this person I knew as “DAD” and you knew as a pioneer in “Neutron Diffraction”, by initiating this award for significant accomplishments in neutron scattering.

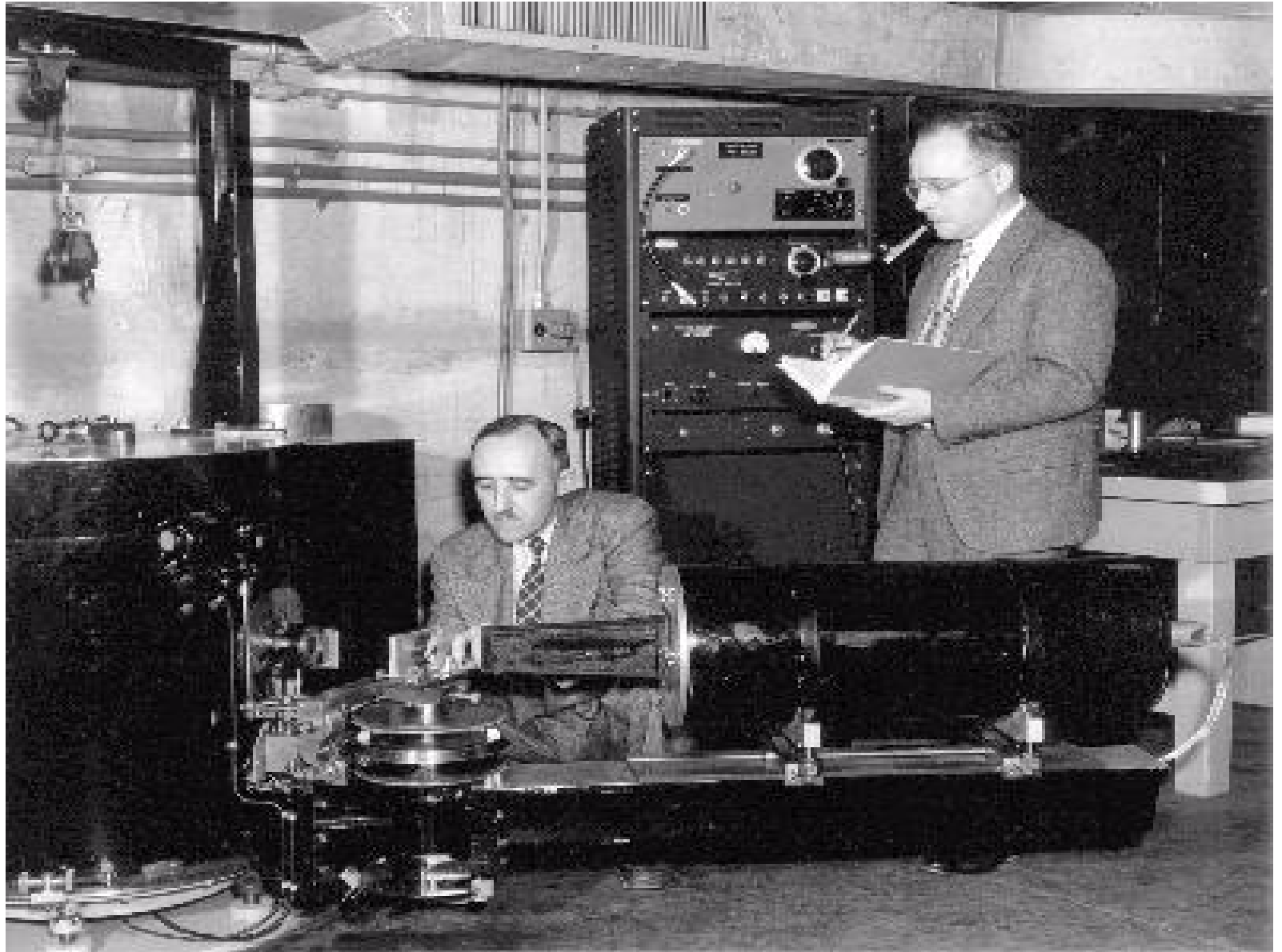
I thought I would show you who this person was through a short photo-summary of his career. If you recognize others in these pictures it should be NO surprise since he not only pioneered this area, but also collaborated and taught many of its ***brightest stars*** who have become leaders in the field.

Cliff Shull grew up in Pittsburgh, received a BS at Carnegie Tech and a PhD from NYU in 1941.



Cliff Shull studying in the faculty club of New York University in 1940.

He then worked for the Texas Co. and after the 2nd World War joined the activity at Oak Ridge in 1946 (joining Ernie Wollan who was a previous student of Arthur Compton, a 1927 Nobel Laureate) and started the area we now know as "Neutron Diffraction."



Ernest Wollan (seated) and Clifford Shull measuring data near an early neutron spectrometer at the Oak Ridge National Laboratory in 1949.

In 1955 he spent a year at Brookhaven National Laboratory (while the reactor at MIT was being built) and then joined MIT in 1956 (as a full professor) where he remained until becoming emeritus in 1986).



Mike Wilkinson, Ernie Wollan, Wally Koehler, and Cliff Shull at ORNL in 1976.

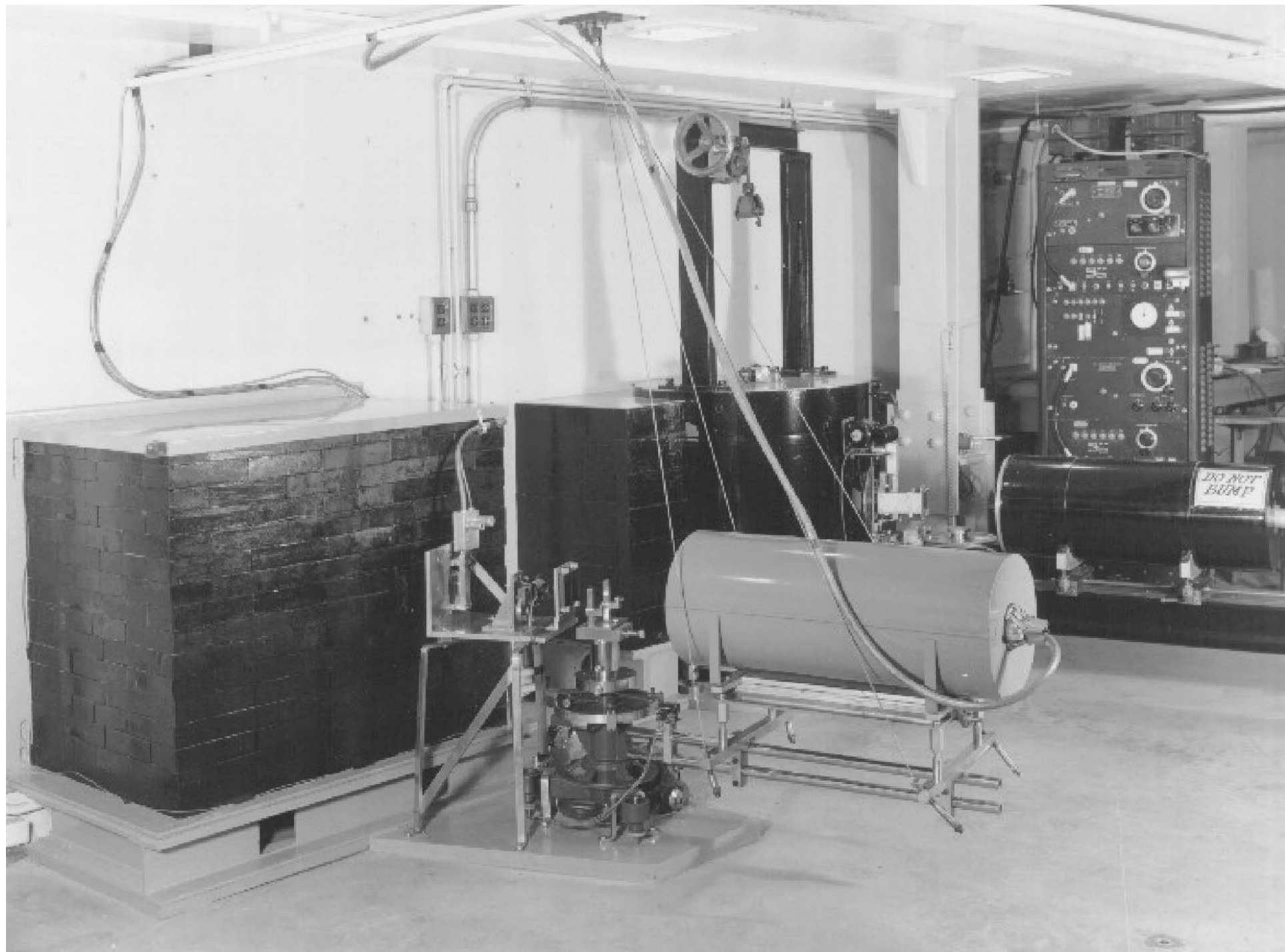
During this time, it's amazing all the "firsts" that he was part of. In fact, while cleaning out my parent's house last year, I saw a publication list of his, and was impressed by all the items I'm sure you will recognize, but which I didn't know anything about. Let me just read a few of these accomplishments:

(1) In addition to his pioneering work demonstrating that neutrons could be diffracted from polycrystalline and crystalline solids, he also **first** explained how the diffracted intensities could be understood.

(2) He measured the coherent scattering amplitude of over 50 different elements in the period of only a couple years! An absolutely amazing feat.



Cliff Shull working on neutron spectrometer at ORNL in the early 1950s.



(3) He provided the **first** direct evidence for the structure of the ice crystal.

(4) He provided the **first** full description of neutron **magnetic** scattering by magnetic crystals.

(5) He provided the **first** direct evidence for the existence of an “antiferromagnetic” state (predicted earlier by Louis Néel, Nobel Laureate-1970 Physics).



- (6) He showed the magnetization in a crystal (of even a pure element like Fe) varies with location in the crystal (even containing regions of "reversed" magnetization).
- (7) He **first** showed the existence of a novel neutron spin-neutron orbit interaction.
- (8) He increased by six orders of magnitude the resolution for charge neutrality of the neutron.
- (9) And he developed a neutron interferometer which showed the dynamical theory of diffraction also holds for neutrons.





Research group at MIT in 1983. Pictured are John Arthur, Anton Zeilinger, Cliff Shull, Michael Horne, Daniel Greenberger, Kenneth Fenkelstein, and Anthony Klein (left to right).

For all of this work, my dad received many awards and honors, including:

Buckley Prize (1956) - American Physical Society

Elected to the: American Academy of Arts & Sciences (1956) and the National Academy of Science (1975)

Humboldt Senior Scientist Award (1979)

Distinguished Scientist Award (from the Governor of Tennessee): 1986

Gregori Aminoff Award (a Nobel-Class award in crystallography): 1993



J. Michael Rowe (left) showing Clifford Shull the new Center for Neutron Research at the National Institute of Standards and Technology in 1995.

Alvin Trivelpiece,
Ralph Moon & Cliff
Shull (left to right)
examining original
neutron spectrometer
at ORNL in 1995.



First recipient of the I.M. Frank Prize
(Russian Nobel Laureate:1958 Physics):
1994

And, of course, the Nobel Prize in Physics
in 1994

He was the consummate experimentalist and teacher. He was extremely honest (almost to a fault) and he had a great sense of humor (PICTURE #14: Pre-Nobel Ceremony with C.G. Shull wearing ballcap), as seen here when he suggested going into the Nobel Prize Ceremony dressed as you see him. Most importantly, he never took himself too seriously.

Herb Bernstein from the University of Massachusetts put it best when he said, "Cliff was great because he was all about doing ***Physics the Right Way***: It was NOT about getting the right answer; It was all about understanding the science of the uncertainties, i.e. finding out ***why*** things did NOT agree."



Cliff Shull in proposed attire just prior to the Nobel Prize awarding ceremony at the Stockholm opera house in 1994.

And finally as Sam Werner from the University of Missouri expressed it so clearly “Cliff showed us how to be an experimentalist, and he showed us how to do it with humility!”

I think my father would be embarrassed by this award in his name.

However, he always felt people built on the foundations of other people, and he was certainly the “Foundation of Neutron Scattering.” You do him honor with this award, and you do honor to those who follow as recipients. It is right to do so!!!

And it is appropriate to announce this award here so close to where it all began in Oak Ridge.

Thank you all.



Cliff Shull with nieces Miriam, Minnie, and Laura Shull and daughter-in-law Mary Shull (left to right) just after receiving the 1994 Nobel Prize in Physics from the King of Sweden.